Channel-Floodplain Disconnection on the Stanislaus River: A Hydrologic and Geomorphic Perspective

KATRINA S. SCHNEIDER

Energy and Resources Group, 310 Barrows Hall, University of California, Berkeley, CA 94720

G. MATHIAS KONDOLF AND ANTHONY FALZONE

Dept. of Landscape Architecture and Environmental Planning, Hearst Field Annex, Bldg. B, University of California, Berkeley, CA 94720-2000

ABSTRACT. The Stanislaus River, the northernmost major tributary to the San Joaquin River, has undergone profound alterations to its flow regime, channel form, and ecosystems. New Melones Dam (built in 1979) and over 30 smaller dams cumulatively impound 240% of average annual unimpaired runoff, reducing winter floods and spring snow melt runoff, and increasing summer base flows to supply irrigation demand. The frequency and extent of overbank flooding has consequently been reduced. Aerial photographs document reduced channel complexity and extensive encroachment of riparian vegetation into the formerly active channel from 1937 to 1998. Limited historical data and field evidence suggest the channel incised approximately 1-3 ft. since dam construction, so the discharge needed for overbank flows has approximately doubled, further isolating floodplains from the channel, and leading to the loss of important habitats. To reestablish overbank flooding and its attendant ecological benefits, both re-operating New Melones Dam to increase high flows in the river, and setting back or breaching levees to reduce the elevational difference between the floodplain and channel, will probably be needed.

INTRODUCTION

The Stanislaus River is one of three principal tributaries to the San Joaquin River (Figure 1), draining 1100 mi^2 on the western slope of the Sierra Nevada, with 40% of its basin above the snowline (USACE, 1999). The basin has a Mediterranean climate with dry summers and about 90% of the precipitation falling November - April. Over 40 dams cumulatively impound 240% of average annual runoff. Of this, 1.2 million acre feet (maf), or 85% of total storage capacity is in New Melones Reservoir (Figure 2, Table 1).

Before large scale human settlement and alteration, the alluvial Stanislaus River was flanked by periodically inundated floodplains, and terraces, with large gravel bars, sloughs, oxbows, and riparian forests and wetlands (Nedeff, 1984). The river supported runs of spring- and fall-run Chinook salmon (*Oncorhynchus tshawytscha*). The Stanislaus spring-run were extirpated by 1912, when Goodwin Dam cut off their natal spawning grounds, which were in higher elevation reaches. Populations of fallrun Chinook salmon (which spawn in the lower alluvial reaches) declined from 35,000 spawning fish in 1953 to fewer than 300 in 1991 and 1992. Loss of dynamic fluvial processes, such as flood scouring and overbank floods, meander migration, and the recruitment of coarse sediment supply to the active channel (Calfed, 1999) is hypothesized to be largely responsible for these population reductions. Although the run has increased in wet years since 1995, the continued survival of chinook salmon in the entire San Joaquin River system is uncertain, and it is a candidate for ESA listing (Calfed, 1999).

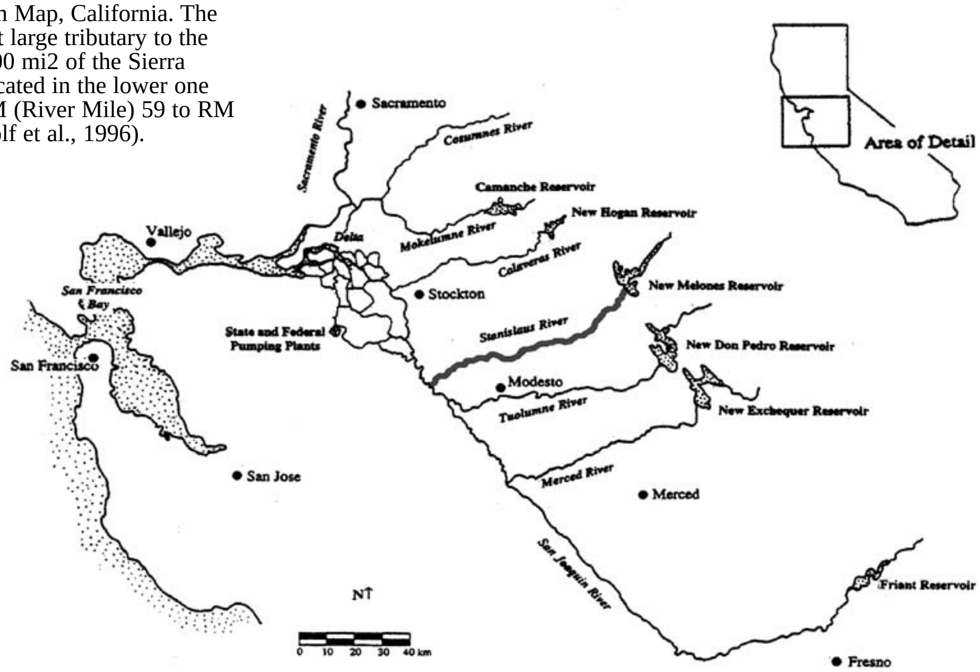
The objective of this study was to analyze hydrologic data, field evidence, and historical evidence (e.g. aerial photographs) to document changes in physical processes and forms relevant to ecological habitats along the alluvial Stanislaus River in the 20th century.

METHODS

Hydrology

We analyzed changes in flow resulting from dam construction, notably Old Melones Dam (1926), the Tri-Dams Project (1957), and New Melones Dam (1979) (Figure 2). We developed and analyzed a composite record from several gauges near Knights Ferry that operated for different historical periods, and 1) plotted annual hydrographs (for extremely wet, wet, dry, and critically dry years); 2) conducted a flood frequency analysis; 3) conducted a flow duration analysis; and 4) plotted average monthly flows. We also summarized peak flows that occurred before 1934, and between the 1937, 1957, and 1997 aerial photographs we analyzed. Although the 1937 photographs did not represent "pre-impact" conditions on the Stanislaus, they were the earliest photographs available.

FIGURE 1. Stanislaus River Location Map, California. The Stanislaus River, northernmost large tributary to the San Joaquin River, drains 1,100 mi2 of the Sierra Nevada. The study reach is located in the lower one half of thewatershed, from RM (River Mile) 59 to RM 41. (Map adapted from Kondolf et al., 1996).



TABLES

TABLE 1. Pre- and Post- New Melones Dam flows of various return intervals.

Q Return Period (Q_{yrs})	Approximate Flow (cfs) Pre-New Melones Dam *	Approximate Flow (cfs) Post-New Melones Dam *
$Q_{1.5}$	5,380	1,840
Q_2	9,430	3,070
Q_5	19,100	5,300
Q_{10}	35,000	6,600
Q_{25}	60,000	7,350 + **

*: Values based on interpolation from the Flood Frequency Analysis
**: There is not sufficient data to estimate the 25 year return flow due to only 21 years of post New Melones Dam flow data

TABLE 2. Peak Flows in Intervals between Aerial Photographs Analyzed. (*Data source: USGS National Water Data Storage and Retrieval System: http://waterdata.usgs.gov/*).

Years	Total Years	% Years Peak over 8,000 cfs	% Years Peak over 16,000 cfs	Max Flow (cfs)	Max Flow (date)
1904-1937	34	68%	32%	64,500	3/19/1907
1938-1957	20	60%	25%	62,900	12/23/1955
1958-1978	21	29%	14%	40,200	12/24/1964
1979-1998	20	0%	0%	7,350	1/03/1997

Geomorphic Investigations/Air Photo Analysis

We compared the earliest aerial photographs available (1937) with photos preceding (1957), and following (1998), construction of New Melones Damto identify historical channel and floodplain features, their changes over time, and land use changes. For three reaches, we digitally adjusted 1937, 1957, and 1998 photos to equivalent scales and rectified the images to illustrate channel changes and floodplain land-use changes over the past sixty years.

We documented channel form and riparian vegetation distribution on Knights Ferry (RM 54) and Oakdale (RM 41) float trips in 2000 noting field evidence of incision (such as root crown exposure). Surprisingly for such large river, the only historical cross section data available to document bed elevation changes were surveys by the California Department of Transportation (Cal Trans) at Orange Blossom Bridge in 1980 and 1993. However, we did not survey the bed under the bridge again because 315 yd^3 of gravel had been added there to improve spawning habitat in 1999 (Mesick, 2001).

RESULTS

Hydrology

Since 1979, the annual peak flows of the Stanislaus River were distinctively smaller, with New Melones and upstream reservoirs absorbing winter and snowmelt flood flows (Figure 3), gradually releasing water down in the summer irrigation season. The floods with return intervals of 1-5 years (in many rivers considered the "channel forming" flows because they move the most sediment over time (Leopold et al., 1964)) were 3-4 times smaller since the construction of New Melones Dam (Table 1). A flow duration analysis for the pre-dam (1903-1926) and post-dam (1979-2000) periods shows essentially no change in median and smaller flows since dam construction, but large reductions in the bigger floods. Comparison of annual hydrographs shows that the flatter post-1979 hydrographs lack winter rainfall peaks, snowmelt peaks, and snowmelt recession limbs (Figure 4). Likewise, post-dam mean

Figure 2

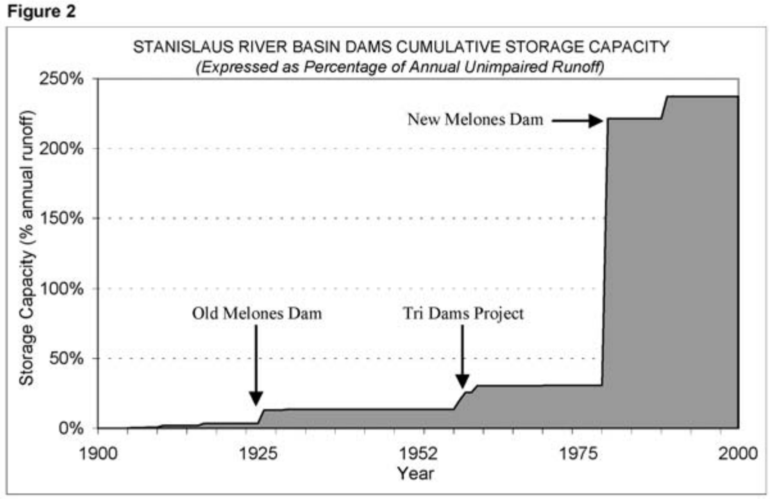


FIGURE 2. Stanislaus River Basin Dams Capacity. Increase in reservoir storage capacity in the Stanislaus River basin (32 dams) expressed as a percentage of mean annual runoff. Total reservoir capacity is nearly 2.85 maf, about 240% of the annual unimpaired runoff of 1.2 maf. (Source: California Department of Water Resources, 1993).

Figure 3

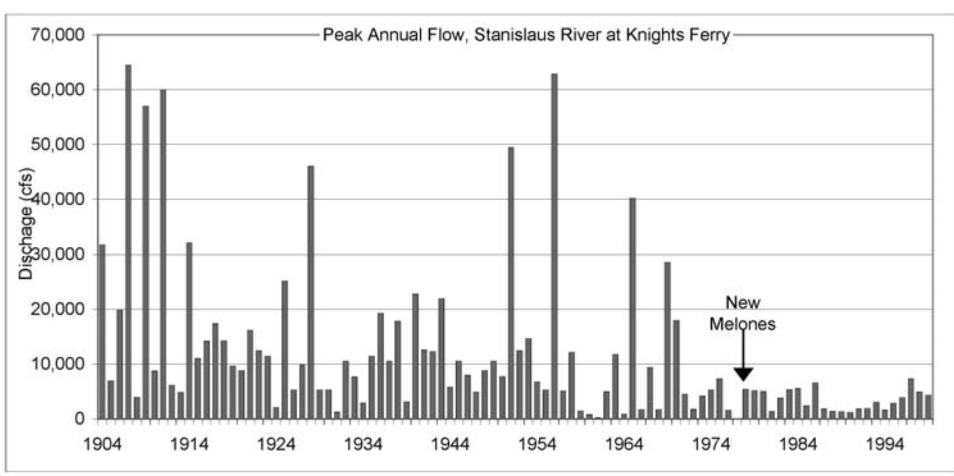


FIGURE 3. Annual Peak Flow, Stanislaus River at Knights Ferry, 1904-1999. Compiled using peak flow data from the gauges: Stan River near Knights Ferry (#11300000) 1904-1932; Melones Powerhouse (#11299500) 1933-1955; and Goodwin Dam near Knights Ferry (#1102000) 1956-1999. (Data source: US Geological Survey).

monthly flows are lower in winter and spring, and higher in summer and fall (Figure 5).

Air Photograph Analysis

Sequential air photographs from 1937-1998 near Knights Ferry (RM 54.7 to RM 53.1) illustrate the nature of channel changes that have occurred on the Stanislaus River (Figure 6). In 1937, unvegetated alternating bar sequences adjacent to the river channel were visible, with discontinuous woody bank vegetation, and unvegetated point bar (A) on the left bank, and open gravel bars at B, C, and D suggesting frequent scour by high flows. The 1957 aerial photograph likewise showed an unvegetated active channel and apparently fresh deposition of sand and gravel on the bars and floodplains, presumably due to flood scour (including the effects of a peak flow of 62,900 cfs in December 1955).

By 1998, the unvegetated alternating bars had disappeared, and dense, riparian vegetation armored the banks, forming a continuous wall along the channel. The bar at point B was completely obscured by vegetation and the large bar at point C was fringed by a wall of vegetation. A gravel pit at point D appeared to be partially refilled by deposition of sediment.

Overall, air photos from 1937-1998 show extensive vegetation encroachment in the formerly active channel reflecting a reduction in frequency of flood scour in the channel. Similarly, point bars and floodplain surfaces show less evidence of flood scour. The air photos also show substantial encroachment by urban and agricultural development, particularly orchards, in floodplain areas, thereby altering the natural river channelfloodplain connection.

Field Reconnaissance and Other Estimates

Unfortunately, changes in channel dimensions could not be accurately documented due to lack of pre-dam, baseline cross section data and confounding effects of the addition of over 13,000 tons of spawning gravel at 18 sites between Goodwin Dan and Oakdale from 1996-1999. Cross sections under the Orange Blossom Bridge indicated channel incision of about 1-2 ft. While useful, historical channel changes at bridges may not reflect changes elsewhere in the channel because bridges are often located in unusually straight reaches or at bedrock. When constructed in erodible alluvium, bridges often constrict high flows and induce scour and degradation (particularly around piers) not reflective of other parts of the channel (Kondolf et al., 2001). Field observations between Knights Ferry (RM 55) and Oakdale (RM 41) in April and July 2000 showed extensive exposure of tree root crowns in the bank. These could be evidence of channel incision of 1-3 ft lateral bank erosion, or a combination. At Riffle 58 (RM 45), a historically used chinook spawning site, a set of stairs constructed in the 1990s is now undercut.

FIGURE 4. Annual Comparison of Extremely Wet and Dry Year Hydrographs. The 1904 pre-dam hydrographshowed high peak flows from rain-on snow, both winter and spring floods were reduced by New Melones reservoir. A dry year comparison of 1919 and 1989 shows post-dam reduction in early winter floods and late spring snowmelt peak flows. (Source: 1919 mean daily flow data: USGS gauge #11300000; 1904, 1989, and 1998: USGS gauge #11302000. Year type designations: DWR CDEC annual data (SNS, sensor #65) and McBain and Trush, 2000).

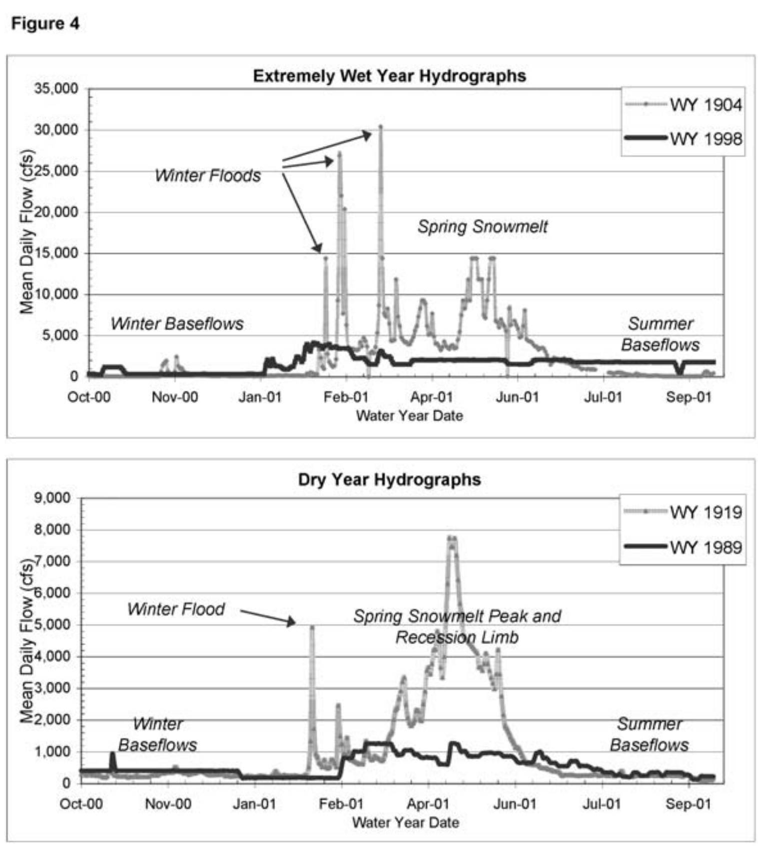


FIGURE 5. Comparison of Average Monthly Flows, Stanislaus River. Average monthly flows pre-Old Melones Dam (1901-1926) were highest in April, May, and June from snowmelt runoff. Post New Melones Dam (1979-1999) monthly flows are more even over the year with historical base flows in September, October and November increased up to five times. (Data Source: Unimpaired flows from "Full Natural Flow," USGS SNS gauge, http://cdec.water.ca.gov. Regulated flows from Indicators of Hydrologic Alteration Model (IHA) analysis of USGS mean daily flow data, Schneider, 2001).

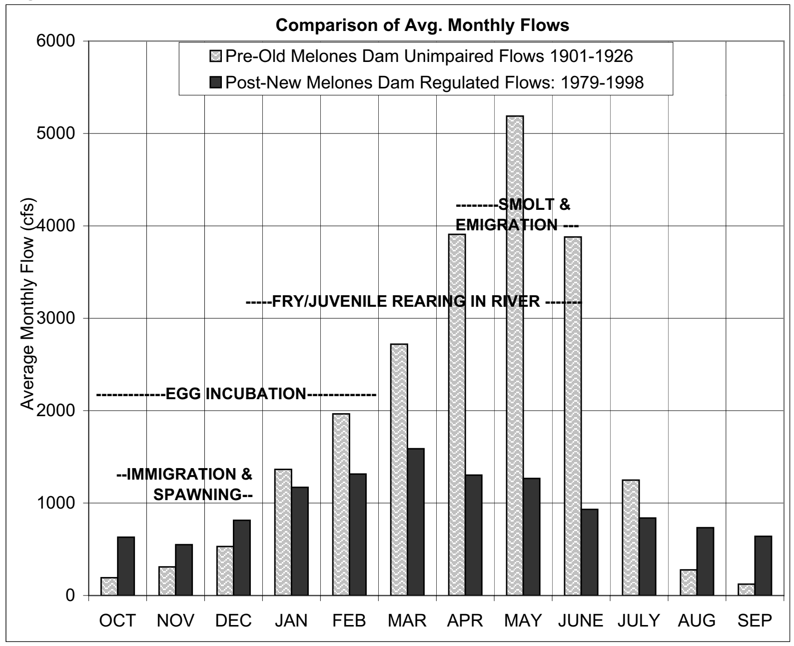
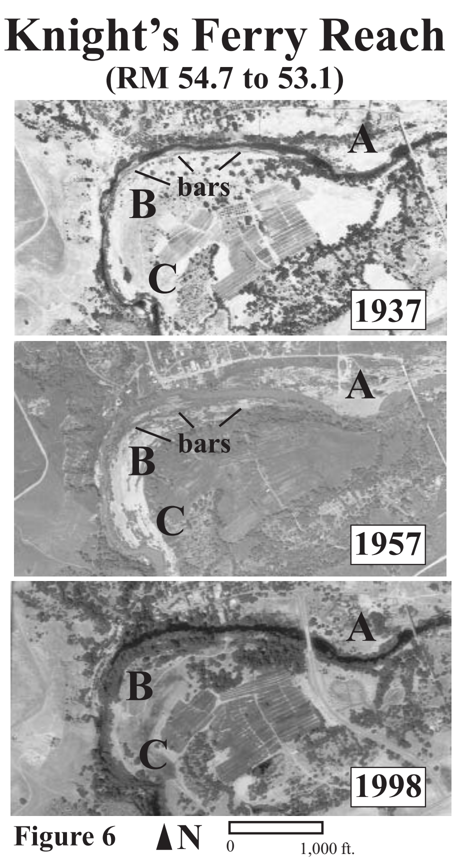


FIGURE 6. Sequential Aerial Photographs of the Stanislaus River near Knight's Ferry. A 1937 aerial photograph shows unvegetated alternative bar sequences adjacent to the river channel, suggesting frequent scour by high flows. In 1957, evidence of scour and deposition from the 1955 flood includes lack of vegetation development along the banks and bars, and deposition of sand and gravel on the bars and floodplains. In contrast, by 1998, open gravel bars had disappeared and were replaced by dense, riparian vegetation on the banks. A gravel pit (approximately 2,600 yd2) is visible at point D and was evidently partially refilled by deposition of bedload.



By assuming 1-3 ft of uniform incision since 1979 and applying the Manning's equation at cross sections R5 and R20, the estimated discharge now required for overbank flows onto the floodplain is about twice what was needed in the historical unincised channel.

DISCUSSION

Hydrologic analysis, historical aerial photographs, and field evidence indicate that the lower Stanislaus River shifted from a dynamic river system, characterized by frequent deposition and scour, to a relatively static and incised system after construction of New Melones in 1979. Post-1979 annual hydrographs were flatter, with reduced peak flows and increased summer baseflows, with consequent vegetation encroachment in the formerly active channel and decreased frequency of overbank flooding. At least partially in response to the reduced flooding regime, urban and agricultural developments have encroached on the floodplain, up to the channel margins in many places. The reduced flood magnitude combined with 1-3 ft. of channel incision mean the river channel is no longer hydrologically or geomorphologically connected to its floodplain.

The direct hydrologic (and indirect geomorphic and land-use) changes effected by New Melones Dam are superimposed upon the geomorphic effects of sediment starvation below dams that trap sand and gravel supplied from the watershed, and in-channel and floodplain mining of sand and gravel at rates nearly ten times greater than pre-dam coarse sediment supply from the catchment.

The functional isolation of floodplain lands from the river channel along the Stanislaus River has been due mostly to reduced high flows, and less so to channel incision. More extensive and precise channel surveys, and application of hydraulic models, could better quantify how these changes alter the frequency of connection between the river channel and the broader floodplain, providing further insights into how these hydrologic and geomorphologic changes may have affected riverine ecology. Research in other alluvial rivers (e.g. Ward and Stanford, 1995) suggests that the loss of open gravel bars and pioneer stage vegetation, and the disconnection of river channels and floodplains would result in reduced habitat complexity and ecosystem degradation.

LITERATURE CITED

CALFED Bay Delta Program. 1999. Ecosystem restoration program plan. Vol. 2: ecological management zone visions. Draft PEIS/EIR technical appendix. Sacramento, CA.

California Department of Water Resources. 1993. Dams within jurisdictions of the State of California. Bulletin No. 17-93. Sacramento, CA.

California Department of Water Resources. 2001. California data exchange center. [http://cdec.water.ca.gov]. Stanislaus River at Goodwin (SNS) gauge, sensor no.65.

Kondolf, G.M., J.C. Vick, and T. Ramirez. 1996. Salmonid spawning habitat restoration in the San Joaquin River basin, California: an evaluation of project planning and success. Report No. 90, Centers for Water and Wildland Resources, University of California, Davis, June 1996.

Kondolf, G.M., A. Falzone, and K.S. Schneider. 2001. Reconnaissance-level assessment of channel change and spawning habitat on the Stanislaus River below Goodwin Dam. Report to the USFWS Anadromous Fish Restoration Program. Berkeley, CA.

Leopold, L.B., M.B. Wolman, and J.P. Miller. 1964. Fluvial processes in geomorphology. W.H. Freeman and Sons, San Francisco.

McBain and Trush. 2000. Habitat restoration plan for the lower Tuolumne River corridor. Report to the Tuolumne River Technical Advisory Committee.

Mesick, Carl. 2001. Personal communications.

Nedeff, N.E. 1984. The historic extent of riparian forest vegetation along the lower Stanislaus River, California. Masters thesis, Dept. of Geography, UCB.

Schneider, K.S. 2001. An assessment of hydrologic and geomorphologic alteration on the lower Stanislaus River. Masters project, Energy and Resources Group, UCB.

USACE. 1999. Sacramento and San Joaquin River Basins, California, post-flood assessment. Sacramento District, March 1999.

U.S. Geological Survey. 2000. National water data storage and retrieval system. [http://waterdata.usgs.gov/]

Ward, J.V. and J.A. Stanford. 1995. Ecological connectivity in alluvial river ecosystems and its disruption by flow regulations. Regulated rivers, research and management 10:105-119.